Bioacoustic Absorption Spectroscopy:
Bio-alpha Measurements off the West Coast

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LONG-TERM GOALS

Demonstrate the significance of bio-alpha, attenuation due to large numbers of fish, on attenuation, transmission loss, scintillation index and reverberation in the ocean through at sea measurements and theoretical models.

OBJECTIVES

Determine the effects of fish with swim bladders on attenuation (bio-alpha), transmission loss (TL), scintillation index (SI) and reverberation through an experiment off the west coast of the USA, and theoretical modeling. Demonstrate the effectiveness of range dependent (moving source) TL measurements for inferring bio-alpha - *all previous bio-alpha measurements were conducted with fixed sources and receivers*. Determine the effects of hake, a physoclists (volumes of their swim bladders are independent of depth) on bio-alpha, TL and SI - *all previous bio-alpha experiments were conducted on physostomes* (volumes of their swim bladders decrease with depth). Infer number densities of fish from bio-alpha measurements for comparison with number densities derived from echo sounder and trawl surveys. Determine effects of bio-alpha on reverberation.

APPROACH

Biacoustic Absorption Spectroscopy (BAS) measurements were conducted from the RV New Horizon in August 2012 in the vicinity of the shelf break at 42.4 N, at a biological hot spot where the concentration of hake was determined to be relatively high. The location of this hot spot was derived from echo sounder and trawl measurements conducted by the Northwest Fisheries Science Center (NWFSC), which were conducted several weeks before the BAS experiment. The location of this hot spot was confirmed with an echo sounder survey, conducted from the RV New Horizon, a few days before the BAS experiment. The selected track was about 254 m deep, relatively flat, and approximately parallel to shore.

We employed low frequency (LF) and mid-frequency (MF) broadband sources (LF: 0.2-1.5 kHz) and MF: 1.5-5 kHz), which were provided by R Gauss of the Naval Research Laboratory (NRL) to generate a series of CW signals between 220 Hz and 5 kHz at source levels below 180 dB, and EARS buoys, which were provided by J Schindall of NRL, to receive and record the CW signals. The configuration of the bio-alpha experiment is illustrated in Figure 1. These sources were programmed to

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transmit sixty CW tones between 220 Hz and 5 kHz (220, 233, 247…Hz) (f_{N+1} =1.059 f_N) over about 10 minutes, every 10 minutes. The duty cycle was 10 %.

We deployed thermistor strings along the receiving array and at the ends of the measurement tracks, to permit measurement of the temporal evolution of average sound speed profiles along the propagation path.

We conducted measurements of TL vs. range (0-10 km) and frequency (0.22-5 kHz), 4 times at night, and 5 times during day. The transit speed was 3 knots. The depth of the sources was about 95 m.
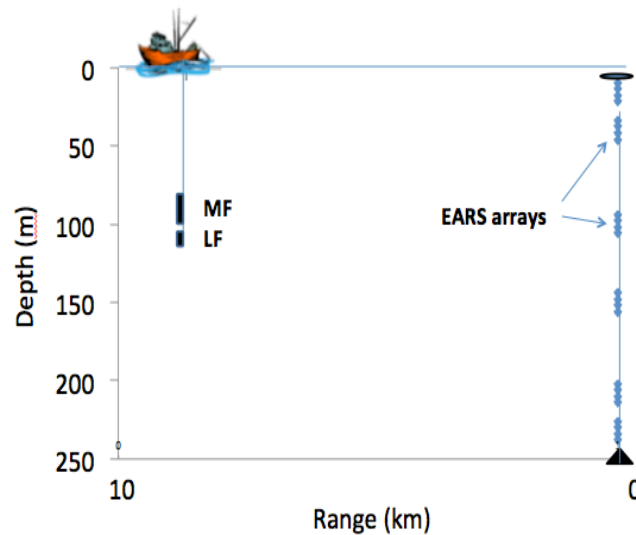

Figure 1. Spatial configuration of broadband sources and vertical receiving array, which were deployed between a float and an anchor in 254 m of water.

We conducted concurrent measurement of fish layers from the RV New Horizon with a hull mounted echo sounder, which was provided by the Scripps Institution of Oceanography and data processing software, which was provided by M Jech of the Northeast Fisheries Science Center. These measurements revealed that there was a layer of fish (probably hake) near the bottom during the day, and that fish (probably hake) were distributed throughout the water column at night. These observations are consistent with historical measurements of the diurnal migration patterns of hake (Alverson and Larkin, 1969), and the concurrent NWFSC survey.

NWFSC trawls revealed that hake was the dominant species at this measurement site. Two year old, 31 cm long hake were most frequently sampled; the frequency of occurrence of one year old and older year classes (> 2 yr) was much smaller (Chu, 2013). Hake exhibit strong avoidance of trawling gear; consequently measurements of frequency of occurrence vs. length may have been biased by mesh size and length (fish speed) dependent avoidance (Best, 1963; Numallee, 1991). Measurements of the average length vs. age, however are considered relatively robust. Figure 2 provides measurements of the length vs. age of hake (Chu, 2013). Lengths of hake increase rapidly with age at ages < 4 year, and slowly with age at ages > 4 year. As a result, it may be possible to identify absorption lines with a sufficiently high value of Q (Q = $f_0/\Delta f_0$ where f_0 is the resonance frequency and Δf_0 is the -3 dB width) due to juveniles (which are 1, 2 and possibly 3 year old), whereas the contributions from hake adult (> 4 year old) hake would most likely result in a broad absorption line with a relatively low Q due to multiple year classes.
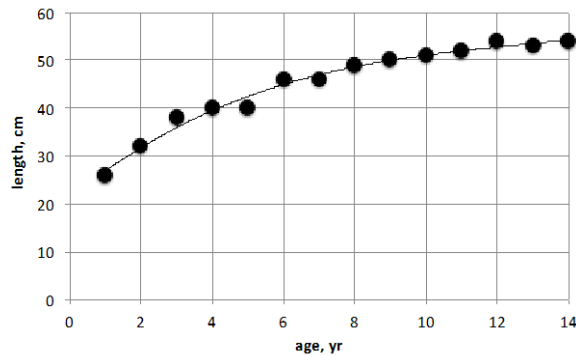
Figure 2. Length vs. age of hake trawled by NWFSC (Chu, 2013).

WORK COMPLETED

We analyzed measured signal and ambient noise levels and determined that the signal to noise ratio is sufficiently high for a sufficiently high percentage (> 90 %) of the data to permit analysis of TL at ranges between 1 and 10 km and frequencies between 0.3 and 5 kHz. We calculated the attenuation coefficient, A, vs. frequency and depth during night and day.

Values of A were derived by correcting measured signal levels for cylindrical spreading loss and chemical absorption loss. Absorption lines are hypothetically due to bio-alpha. A was found to be strongly dependent on frequency and approximately independent of depth during the day, and relatively small and approximately independent of frequency and depth at night. During the day, when hake concentrated in a thin layer above the bottom, A was as high as 1.3 dB/km. At night, when hake were distributed throughout the water column, A was much smaller, viz., - 0.25 ± 0.35 dB/km, at frequencies below 2.4 kHz. The average value of the systematic bias, - 0.25 dB/km, suggests that the departure from cylindrical spreading was significant but small, and that the attenuation due to the bottom was small. The standard deviation of the bias was ± 0.25 dB/km.

RESULTS

Figure 3 provides a comparison of measurements and theoretical calculations of depth-averaged values of A. Theoretical calculations correspond to resonance frequencies of 0.75, 0.9 and 1.05, 1.8 kHz and 2.9 kHz. Resonances at the three lowest frequencies are hypothetically due to adult hake. The resonance at 1.8 kHz is hypothetically due to juvenile hake. The resonance at 2.9 kHz is due to an unknown species. The assumed value of Q of the absorption lines associated with hake was 9; whereas the Q associated with the absorption line at 2.9 kHz was 7. Resonance frequencies, values of Q, and magnitudes of α at resonance frequencies were selected to fit the data. The measured absorption line centered at 0.9 kHz may also be modeled as a single absorption line with a lower value of Q.
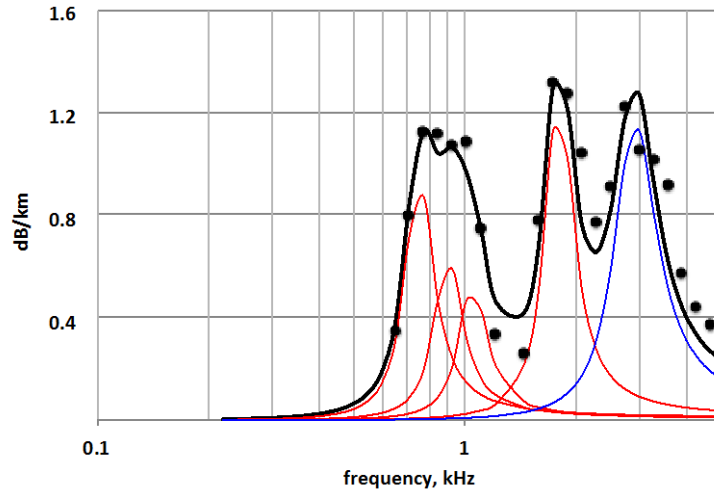
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Figure 3. Depth averaged values of attenuation coefficients, A, during the day and theoretical calculations for swim bladders with resonance frequencies of 0.75, 0.9 and 1.05 kHz hypothetically due to adult hake, 1.8 kHz hypothetically due to juvenile (2 year old) hake, 2.9 kHz due to an unknown species (blue), and the sum (in black).

Resonance frequencies of 0.9 and 1.8 kHz at 250 m correspond to r equal to 2.1 and 1.05 cm respectively (Diachok, 1999). Figure 4 shows the relationship between r and length of hake, which were derived from laboratory measurements by Henderson and Horn (2007), and inferences of r from measured absorption lines. Inferred values of the effective radii, r, of swim bladders associated with measured absorption lines are in good agreement with laboratory measurements. In particular, the absorption line at 1.8 kHz is consistent with juvenile, 2 year old, 31 cm hake, the most frequently sampled year class and size, whereas the broad absorption line at 0.9 kHz is consistent with the average length of adult hake older than 5 year, 50 cm.
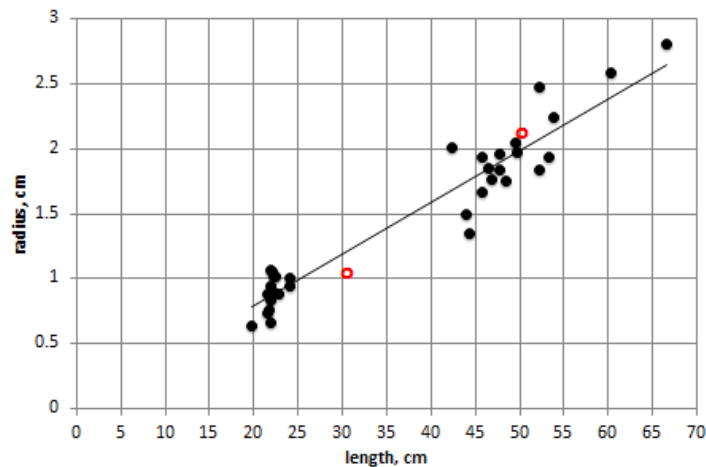

Figure 4. Effective radius, r, vs. length of hake derived from laboratory measurements by Henderson and Horn (2007) (black), a linear fit to their data, and inferences of r, based on theoretical fits to measured absorption lines (red).

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Values of bio-alpha within the absorption layer may be estimated from the equation, $\alpha = AD/t$, where α is the attenuation coefficient in the layer, A is the depth averaged attenuation coefficient, D is the ocean depth (254 m), and t is the average thickness of the layer (~10 m). Number densities may be calculated from the equation, $\alpha = \frac{1}{2} n\sigma$, where n is the number density and σ is the extinction cross section (Diachok, 1999).

Results to date indicate that that range dependent measurements of TL are suitable for inferring the effects of bio-alpha on TL, hake have a measurable effect on affect TL, and bio-alpha measurements permit isolation of the effects of juvenile and adult hake in frequency space. Future work will include 1) extension of this analysis to TL measurements at higher frequencies, where other species contribute to bio-alpha, 2) derivation of values of bio-alpha, layer depth and layer thickness through comparison of measurements and calculations of transmission loss, 3) comparison of number densities of juvenile and adult hake derived from bio-alpha and NWFSC echo sounder and trawl measurements (in collaboration with D. Chu of NWFSC), 4) calculations and analysis of the causes of the scintillation index (Diachok, 2005), and 5) analysis of the effects of bio-alpha on reverberation (in collaboration with R. Gauss of NRL).

IMPACT/APPLICATIONS

The performance of Navy sonars is strongly affected by attenuation and reverberation due to scattering by marine organisms, specifically fish with swim bladders, in biologically intense environments, such as the Yellow and East China Seas. Existing Navy sonar performance models do not account for the effects of bio-alpha on transmission loss (TL) or reverberation. The proposed research is expected to provide the experimental basis for including bio-alpha in the Navy's performance prediction models.

Bioacoustic Absorption Spectroscopy (BAS) has the potential to permit classification of fish by size (adults vs. juveniles) during routine fisheries surveys conducted by NOAA Fisheries Science Centers.

This experiment demonstrated that bio-alpha may be inferred from range-dependent (moving source) measurements - *all previous bio-alpha experiments were conducted with fixed sources and receivers*. This result has important implications for both naval and fisheries applications.

RELATED PROJECTS

The results of this project are expected to transition to the projected Spawar AEMBERS Project, which is designed to assess and exploit marine bioacoustic effects on the Navy's sonar systems.

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